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Shaping tomorrow's problem solvers

At the Naval Postgraduate School, O.R. theory is put into practice, helping officers make tactical, operational and strategic decisions that impact the nation's security.

By Jeff Kline

It is the first day of the Joint Campaign Analysis class at the Naval Postgraduate School (NPS). I look from the teaching podium to the faces of my graduate students – a mixture of U.S. Army, Navy, Marine Corps, Air Force and Allied officers midway through their graduate degree programs in operations research, operational logistics, modeling and simulation, systems engineering analysis and acquisition. Most have completed a year of statistics, probability, programming, simulation, optimization, physics and engineering courses and are now ready for the "so what?" And with this crowd, that is important.

These are professional officers, most with more than four years of operational experience, assigned to the NPS to obtain graduate degrees that will enhance their contributions to their nation's security. They may enjoy theory, but theory's value is measured by how it serves them in solving real-world problems. Their previous NPS instructors appreciate these students' backgrounds and ensure their

courses are reinforced with practical examples on use of optimization, data analysis, simulation or whatever analytical discipline is the subject of each class. My challenge is different. It starts with the problem and demands the students employ their "tool kit" to provide the best analysis for critical decisions that need to be made.

I start my class with a story.

The year is 2024 and the United States finds itself in a major conflict at sea with a country possessing a capable submarine force. Commander Tom W. Hebner, captain of the destroyer USS William P Lawrence (DDG-110), sits in his combat information center monitoring his ship's defense of the aircraft carrier USS Gerald R Ford (CVN-78). Exhausted from days of action, yet alert, our captain sits up when he hears from his sonar gang, "Sonar contact bearing 010, range ten thousand yards."

His antisubmarine evaluator reports, "Captain, that puts the contact within the torpedo danger zone of the carrier. I recommend an urgent attack."

An urgent attack is called for when an unknown and unevaluated acoustic contact, which could be a submarine, is within attack range of the carrier (or other high-value ship). Time to refine and further evaluate the contact to ensure it is a submarine, and then obtain a better targeting solution, is an unaffordable risk. If the contact is a submarine, it may be ready to launch a weapon against the carrier.

Captain Hebner knows all this, but there is a problem. This is the fourth urgent attack he has conducted in six days, all against unconfirmed contacts, and his inventory of torpedoes is low. He must now weigh his scarce torpedo resources against the risk of taking time to further evaluate the contact and possibly putting the carrier in danger. His antisubmarine evaluator is aware of this situation and says, "Sir, we have a Submarine Combat Air Patrol (SUBCAP) on station, an F/A-18 armed with four, 500-pound SUBOMBS. I recommend we vector him to drop them in the center of our contact's estimated position to conduct the attack." Realizing this will save his few torpedoes for a better attack solution, Captain Hebner holds fire and directs the F/A-18 to drop his weapons.

And here is where I get interrupted. My F/A-18 pilot student, with pity in his face for the old, out-of-touch instructor says, "I am sorry to interrupt, sir, but a SUBOMB does not exist nor does anything called a SUBCAP." Ah ha! I have them.

"Of course not," I respond, "but should it? During the Falkland war the British ran very short of expensive torpedoes conducting urgent attacks against unknown contacts because they had no other choice. Should we learn from them? Should we augment our expensive and very effective torpedoes with a much less expensive and admittedly less effective weapon such as a modified 500-pound bomb for just these tactical situations? After all, the bombs will let the submarine know we are aware of his presence. We may confuse or deter his attack, make him easier to detect for a follow-on torpedo attack, or, if not a submarine, will scare away the fish, shrimp or whatever is giving us our contact. So, does it make sense to add this capability to our weapon's inventory?"

Naval officers look over a simulation chart. Operations research is a key part of the graduate degree program at NPS.

I receive the anticipated response: "Well, it depends." It depends on the cost and effectiveness of each weapon, how many times we may find ourselves in an urgent attack situation during a long campaign, the anticipated number of false alarms (non-submarine contacts that are not known to be non-submarine), the submarine's weapons capabilities, the monetary limitations on purchasing antisubmarine weapons, how many ships may be assigned antisubmarine warfare missions and other demands on our F/A-18 aircraft. All correct.

We then proceed into seminar on what analytical tools the students can employ to obtain timely estimates in response to these questions. A few early suggestions from the class include data analysis and regression for estimating weapon costs; physics modeling, simulation and optimization for determining weapons effectiveness for each tactical engagement; decision theory for the submarine commander's decision to evade or attack; historical data analysis for false alarm percentages; campaign modeling, search theory and simulation for estimating the number of ships and aircraft assigned to antisubmarine missions that experience urgent attack criteria; and optimization methods to find the best weapon inventory mix. At the end of the seminar I say, "O.K., now do it." And that is when the magic happens: They do it.

Unique Graduate Students

I ADMIT I AM A SPOILED and very lucky professor. My students are paid as military officers, assigned fulltime to obtain a graduate degree, dedicated, motivated and experienced. On the other hand, they rightfully expect a level of professionalism from their instructors commensurate with what that they bring to the classroom. Yes, they want applied relevant examples, but they also want their teachers to be academic leaders in their disciplines and nationally recognized in their own right. NPS instructors know they share the responsibility of shaping the next generation of national leaders who will use their classroom experiences to make tactical, operational and strategic decisions affecting our country. As fellow NPS Operations Research faculty member Dr. Jerry Brown likes to say, "I never forget that one day I'll be working for them."

An example: Admiral Mike Mullen, past chairman of the Joint Chiefs of Staff and NPS O.R. graduate, completed his thesis under Professor Wayne P. Hughes, captain, USN (ret). Speaking during an interview for an INFORMS Podcast in 2010, Admiral Mullen said of his O.R. degree, "...a graduate O.R. education allows me to think much more critically than I had before and really to frame a problem ..." He goes on to say that these skills always help him look at problems a bit differently than those presenting the issues to him and allows him to ask the right questions. A career-long capability to think critically, frame problems and ask the right questions for the best solutions is the main goal for our operations research graduates.

The author makes a point with students at the Naval Postgraduate School.

A Continuum of Analytical Education

NOT ALL OUR STUDENTS are traditional resident scholars, however. The NPS Operations Research Department offers a continuum of analytical educational degrees and short courses for every level of officer and executive. Our degree programs include Operations Research, Joint Operational Logistics, Human Systems Integration, Systems Engineering Analysis and our distant learning Masters of Systems Analysis program, which focuses on delivering a professional practitioner's degree to those not able to attend resident courses. Officers and government civilians with one to 12 years of experience complete these programs. Non-degree programs include a three-course elective series provided to senior officers and civilians at the Naval War College, short three-day workshops on applying analytical methods to strategic planning in our executive courses and one-on-one executive sessions with admirals on risk assessment and quantitative contributions to decision-making. All have one common characteristic: They demonstrate the value of quantitative analysis with relevant examples and present real-world projects and theses that employ quantitative methods. For example, our Masters of Systems Analysis (MSA) students, spread across the globe, self-organize into project teams, offer their services to a defense organization and conduct a graduation project on a challenge or issue provided by that organization (with faculty approval of course!).

Throughout the MSA course of instruction, faculty invite defense organizations to speak to our students via video teleconferencing about their past analytical studies and current challenges. This virtual classroom experience is an opportunity for the students to approach these commands, and it provides practical examples for students to use with their own commands for possible graduation project topics. Just one example involves a systems analysis study completed at the request of Naval Air Systems Command that demonstrates the contribution and cost effectiveness of sensors onboard unmanned vertical takeoff and landing aircraft in counter-piracy operations. As a note, our distant learning students have consistently reported using skills obtained in their classes in their jobs even before graduating.

Practical and Relevant Education

OUR RESIDENT STUDENTS' talents are also well known. They are in high demand for their research time on actual problems. With only a minimum of invitation, organizations from all military services send us topics, issues and problems they want to be addressed during the officer's research quarters at any level of security classification. These organizations wisely seek to leverage the student's time and recently obtained knowledge, accompanied by a faculty advisor's expertise to offer an unbiased, quantitative and many times innovative approach to their problems inside a published thesis. Frequently these theses lead to an independent, funded research program for the advising faculty and follow-on thesis topics for future students.

Our resident Systems Engineering Analysis (SEA) curriculum requires an extensive graduation project that includes coordinating students' efforts from other curricula across campus. These projects are normally provided by a Navy sponsor such as the Chief of Naval Operations' staff, require complex systems design and integration and are briefed to a Navy-wide audience. On more than one occasion, the products of these efforts have provided the foundation to further naval programs. Just one example is the Advanced Undersea Weapons System (AUWS) alternative concept designs provided to the Naval Undersea Warfare Command. NPS O.R. courses that dedicate a large portion of their time to student projects such as wargaming, networks, human factors systems design and joint campaign analysis are also approached by outside organizations desiring to shape the students' course work to address their current operational issues. The students are motivated by having a real-world sponsor inside a course, and the sponsor is rewarded with class analysis, presentations and individual papers summarizing the work. Topics have ranged from vulnerabilities in the undersea cable system (networks class) to how best to use new technologies in expeditionary warfare (wargaming class).

The campus of the Naval Postgraduate School in Monterey, Calif.

NPS faculty may also be the source of practical case studies for class presentation or thesis research projects. Our military and retired military faculty members all have experience applying operations research and management science to tactical, operational and strategic problems. They offer their experiences in case study format as class presentations. Additionally, our civilian faculty, after working defense-related issues for years, may suggest students apply analytic tools to new problems. Applying optimization for ship engineering plant configuration to conserve fuel is one example, and research into social networks is another.

Another source of applied topics is the students themselves. Although in the end almost all students have the final say on the particular research they wish to conduct as projects or thesis work, nothing motivates them more than addressing a topic or problem they have personally confronted in their own service. We have several research chairs at NPS with funds available to sponsor student travel and equipment to address their issues. These projects are particularly interesting to Navy leadership because in many cases the leader is unaware of the problem and always appreciates a recommended solution. The way which Navy ships conduct at-sea search and boarding of other vessels was radically modified as a result of one of these student-originated projects.

Our non-degree Naval War College elective series and our executive workshops borrow case studies and projects from our graduate programs to show non-analysts, but current decision-makers, both the strengths and limitations of quantitative contributions to decision-making. These presentations are formed so the situation and problem are presented first, before analytical information is provided to the decision-maker. Then students are invited to discuss what they would decide or what additional information they want before making the decision. Finally, the outcome is briefed followed by a short summary of any analytical methods or tools used.

The one-on-one executive admiral discussions are probably the most unique because they are tailored to each admiral's upcoming responsibilities. In most cases their next job will involve the "business side" of the Navy, so they show interest in ways business has applied analysis to perform better. INFORMS conferences and publications are a treasure chest for this type of example. With my colleagues, I attend INFORMS conferences to harvest examples of where analysis clearly contributed to better logistics, operations or marketing. INFORMS publications *Operations Research* and *Interfaces* highlighting advancement of the analytical art may excite O.R. professionals, but clear, practical examples excite these senior leaders. *Analytics* magazine and, of course, *OR/MS Today* are also favorite page-turners in discovering ways to communicate the value of quantitative thinking to non-analysts.

NPS faculty members enjoy a unique set of students. However, whether our students are military officers, graduate students at civilian universities or junior business partners, what is common among all instructors and mentors of the quantitative arts is the sense of accomplishment we enjoy when we see these budding analysts' excitement applying quantitative tools to real-world problems. We rightly take pride in shaping a new generation of analysts to help solve the difficult business, government, defense and social issues of the future. That is why I look forward to every teaching day. **IORMS**

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